Section One: Multiple Choice **25 marks (25% of paper)**

1. A catalyst can decrease the time taken for a chemical system to reach equilibrium.
This is best explained by the catalyst:

   A. increasing the energy of the collisions so that a greater proportion result in a chemical reaction.

   B. increasing the enthalpy of the reactants, thereby increasing the frequency of successful collisions.

   C. providing an alternative transition state for the reaction with lower energy.

   D. decreasing the rate of the reverse reaction so that the product is produced more quickly.

2. $PC\ell_5$ is prepared from the reaction between $PC\ell_3$ and $C\ell_2$, resulting in the establishment of the following equilibrium:

$$PC\ell_3(g) + C\ell_2(g) \rightleftarrows PC\ell_5(g)$$

Four different flasks, labelled A, B, C and D, at the same temperature, each contain a gaseous mixture of $PC\ell_5$, $PC\ell_3$ and $C\ell_2$. The concentration, in mol L^{-1}, of these components in each of the flasks is shown below.

In three of the four flasks, the mixture of gases is at equilibrium. In which one is the mixture of gases not at equilibrium?

Flask	$[PC\ell_3(g)]$	$[C\ell_2(g)]$	$[PC\ell_5(g)]$
A.	0.20	0.30	0.15
B.	**0.15**	**0.15**	**0.20**
C.	0.10	0.40	0.10
D.	0.80	0.15	0.30

Need to do a calculation for each one substituting the values in the expression for

$$\mathbf{K = \frac{[PC\ell_5]}{[P\,C\ell_3][\,C\ell_2]}}$$

A, C, and D all = 2.5, B = 8.9

3. Carbon disulfide, CS_2, is used as a solvent for many industrial processes. It can be prepared by heating carbon in the presence of $H_2S(g)$ at high temperatures.

$$C(s) + 2\,H_2S(g) \rightleftarrows CS_2(g) + 2\,H_2(g) \qquad \Delta H = +84.0\ kJ\ mol^{-1}$$

Which of the following would result in an increase in the yield of carbon disulfide?

I	Adding more carbon	**No change to equilibrium**
II	Decreasing the volume of the system	**shifts L**
III	Removal of hydrogen gas from the system	**shifts R**
IV	Increasing the temperature of the system	**shifts R**

A. I and IV only

B. III and IV only

C. I, II and IV only

D. I, II, III and IV

4. When solutions of potassium thiocyanate (KSCN) and iron (III) chloride are mixed, the following equilibrium is established:

$$Fe^{3+}(aq) + SCN^-(aq) \rightleftarrows FeSCN^{2+}(aq) \qquad \Delta H = -ve$$
brown *red*

The intensity of the red colour of the solution could be increased by the addition of:

A.	Ag^+ ions, which form AgSCN(s).	**shifts L to make more SCN^-**
B.	$Sn^{2+}(aq)$, which converts $Fe^{3+}(aq)$ to $Fe^{2+}(aq)$.	**shifts L to make more Fe^{2+}**
C.	a small volume of water.	**shifts L to increase [ions]**
D.	**a small quantity of concentrated $Fe(NO_3)_3$ solution.**	**shifts R to use up Fe^{3+}**

5. The anaesthetic, nitrous oxide (N_2O) decomposes to form an equilibrium mixture of N_2O, N_2 and O_2 according to the following equation:

$$2\,N_2O(g) \rightleftarrows 2\,N_2(g) + O_2(g)$$

At 25°C, $K = 7.3 \times 10^{37}$ and at 40°C, $K = 2.7 \times 10^{36}$

What valid conclusion can be made from this?

A. The equilibrium concentrations of N_2 and O_2 are equal at 25°C.

B. The equilibrium concentration of N_2O is higher at 25°C than at 40°C.

C. N_2O is less stable at the higher temperature.

D. The forward reaction is exothermic.

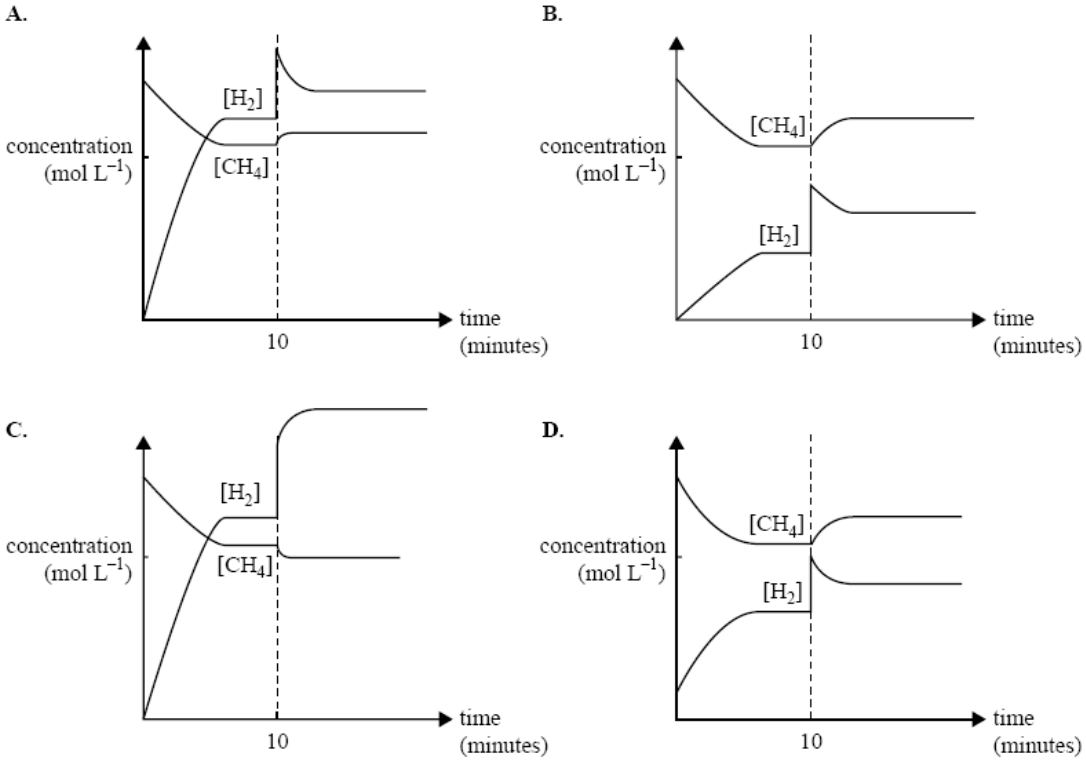
6. The following gaseous equilibrium is established at high temperatures in the presence of a finely divided nickel catalyst.

$$CH_4(g) + H_2O(g) \rightleftarrows CO(g) + 3\,H_2(g) \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

Equal amounts of $CH_4(g)$ and $H_2O(g)$ are added to a reaction vessel and allowed to react and reach equilibrium. At 10 minutes, some $H_2(g)$ is added to the mixture and equilibrium is re-established.

Which one of the following graphs best represents the changes in $[CH_4]$ and $[H_2]$ in the reaction mixture during this time?

ANSWER – A Look at the ratio of H_2 to CH_4, 3:1



7. Consider the equilibrium established in the formation of tetraphosphorous decoxide:

$$P_4(s) + 5O_2(g) \rightleftarrows P_4O_{10}(s) \qquad \Delta H = -\text{ve}$$

Which of the following changes would lead to a new equilibrium with a different final concentration of O_2?

A. Addition of $P_4(s)$

B. Decreasing the surface area of $P_4O_{10}(s)$

C. Addition of $O_2(g)$

D. Decreasing the temperature.

$[O_2]$ cannot change unless the temperature changes as K depends on O_2 only, $K = 1/[O_2]^5$

8. Ethanol can be manufactured by the reaction between ethene and water. This is represented by the equation:

$$C_2H_4(g) + H_2O(g) \rightleftarrows C_2H_5OH(g) \qquad \Delta H = -46 \text{ kJ mol}^{-1}$$

Which conditions would produce the fastest rate for the forward reaction?
NOTE – this question refers to RATE only, not Yield

A. Low pressure and low temperature.

B. High pressure and low temperature

C. Low pressure and high temperature

D. High pressure and high temperature

9. Which of the following correctly identifies the trends in atomic radii, first ionisation energy and electronegativity as you go across period 3 from Na to Cℓ?

	Atomic radii	*First Ionisation Energy*	*Electronegativity*
A.	Increases	Decreases	Increases
B.	**Decreases**	**Increases**	**Increases**
C.	Decreases	Increases	Decreases
D.	Increases	Decreases	Decreases

10. Consider the following successive ionisation energies of elements X and Y.

Element X

Ionisation	1st	2nd	3rd	4th	5th	6th	7th	8th
Ionisation Energy (kJ mol^{-1})	1,310	3,390	5,320	7,450	11,000	13,300	71,000	91,600

Element Y

Ionisation	1st	2nd	3rd	4th	5th	6th	7th	8th
Ionisation Energy (kJ mol^{-1})	577	1,820	2,740	11,600	14,800	18,400	23,400	27,500

The compound formed between X and Y would most likely be:

A. a covalent compound of formula YX_3.

B. an ionic compound of formula Y_2X_3.

C. a covalent compound of formula Y_2X_3.

D. an ionic compound of formula Y_3X_2.

X has 6 valence electrons, eg oxygen, Y has 3 valence electrons eg Al, hence Al_2O_3 / Y_2X_3

11. A molecule formed by atoms with atomic numbers of 7 and 9 will be: **this is NF_3**

A. pyramidal and polar

B. pyramidal and non-polar

C. triangular planar and polar

D. triangular planar and non-polar

12. Molecules of $COC\ell_2$ and SO_3 are both triangular planar. Which one of the following statements is true?

A. Both $COC\ell_2$ and SO_3 are non-polar.

B. Both $COC\ell_2$ and SO_3 are polar.

C. $COC\ell_2$ is non-polar whereas SO_3 is polar.

D. $COC\ell_2$ is polar whereas SO_3 is non-polar. Both are triangular planar

13. Consider the table below showing some data for the halogens.

Halogen	Atomic number	Molecular mass	Melting point (°C)
F_2	9	38	–220
$C\ell_2$	17	71	–101
Br_2	35	160	–7
I_2	53	254	114

Which one of the following statements best explains why the melting points of the halogens increase with increasing atomic number?

A. The number of electrons increases, resulting in the formation of stronger covalent bonds.

B. The increased number of electrons causes the molecules to be more polar.

C. An increased number of protons and electrons lead to stronger dispersion forces.

D. As the molecular mass increases so does the strength of bonds.

14. Consider the alcohols, butan-1-ol and hexan-1-ol. Compared to butan-1-ol, hexan-1-ol would have:

A. a higher boiling point and greater solubility in water.

B. a higher boiling point and lower solubility in water.

C. a lower boiling point and greater solubility in water.

D. a lower boiling point and lower solubility in water.

Hexan-1-ol has a longer chain and larger molar mass, hence higher bpt, lower solubility

15. Which of the following molecules can form hydrogen bonds with water molecules?

I.	methanol	**contains O with 2 lone pairs of e**
II.	ethanal	**contains O with 2 lone pairs of e**
III.	methanamine	**contains N with 1 lone pair of e**
IV.	hydrogen fluoride	**contains F with 3 lone pairs of e**

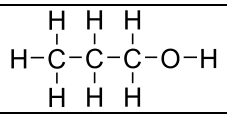
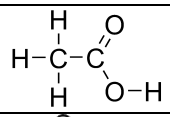
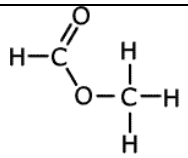
A. I only

B. I and IV only

C. I, II and IV only

D. I, II, III and IV

16. The table shows information regarding three compounds.

Compound	*Structural formula*	*Molar mass (g mol^{-1})*	*Boiling point (°C)*
X		60.1	97
Y		60.1	118
Z		60.1	?

What is the best estimate for the boiling point of compound **Z**?

A. 31°C Z does not have hydrogen bonding hence bpt must be less that other 2

B. 101°C

C. 114°C

D. 156°C

17. Which of the following has a different empirical formula to the others?

Note – Empirical Formula is asked for

A.	**Methylethanoate**	**Molecular F = $C_3H_6O_2$ = Empirical F**
B.	Ethylethanoate	**Molecular F = $C_4H_8O_2$ Empirical F = C_2H_4O**
C.	Butanoic acid	**Molecular F = $C_4H_8O_2$ Empirical F = C_2H_4O**
D.	Ethanal	**Molecular F = C_2H_4O = Empirical F**

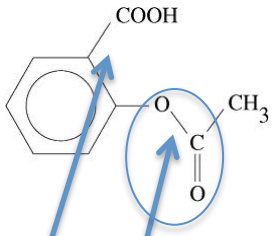
18. How many isomers are there for $C_3H_6BrC\ell$?

A.	3	**the 5 are:**	**1-bromo-1-chloropropane**
B.	4		**1-bromo-2-chloropropane**
C.	**5**		**1-bromo-3-chloropropane**
D.	6		**2-bromo-2-chloropropane**
			2-bromo-1-chloropropane

19. Which one of the following pairs of organic compounds are not isomers?

A.	Pentane and dimethylpropane	**both are C_5H_{10}**
B.	**Methylpropane and cyclobutane**	**C_4H_{10} and C_4H_8**
C.	Ethylhexane and 2,2,4-trimethylpentane	**both are C_8H_{18}**
D.	Cyclohexane and 2-methylpent-1-ene	**both are C_6H_{12}**

20. Aspirin contains the following substance:



Which of the following functional groups does aspirin contain?

I. aldehyde
II. ketone
III. carboxylic acid
IV. ester

A. I and II
B. II and III
C. III and IV
D. I, II, III and IV

21. Which of the following could be oxidised to a ketone using acidified potassium dichromate?

A.	**Cyclohexanol**	**need a 2^o alcohol to form a ketone**
B.	Methyl-2-propanol	**3^o alcohol**
C.	Methanol	**1^o alcohol**
D.	Ethanol	**1^o alcohol**

22. Which of the following pairs of compounds would form 1-propylethanoate when warmed with sulfuric acid?

A. CH_3CH_2COOH and CH_3CH_2OH **forms ethylpropanoate**

B. CH_3CH_2OH and $CH_3CH_2CH_2OH$ **no reaction, both alcohols**

C. CH_3COOH and $CH_3CH_2CH_2OH$

D. CH_3OH and CH_3COOH **forms methylethanoate**

23. Which of the following substances can exhibit geometrical isomerism?

DRAW THE STRUCTURES OUT – see next page

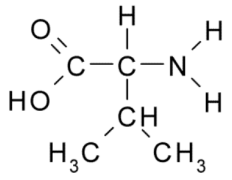
A. 1-fluoro-1-bromoethene

B. Propene

C. 2-methylbut-2-ene

D. 3-methylpent-2-ene

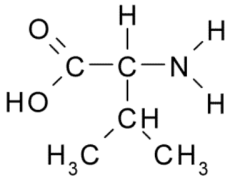
24. A molecule of valine has the following structure:



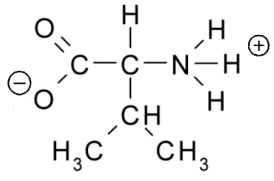
Which of the following best represents the structure of valine when dissolved in a hydrochloric acid solution with a pH of 3?

ANSWER – C $R\text{-}NH_2 + H^+ \rightarrow R\text{-}NH_3^+$

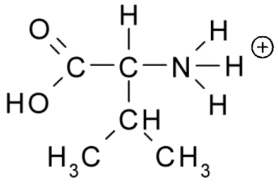
A.



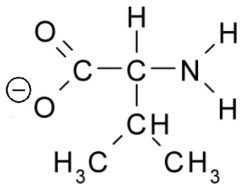
B.



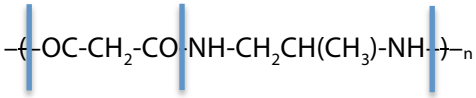
C.



D.



25. A particular polymer can be represented by the formula:



Which of the following pairs of monomers would be required to prepare this polymer?

A. $HOCH_2CH_2CH_2OH$ and $H_2NCH_2CH(CH_3)NH_2$

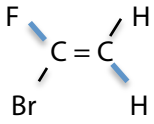
B. $HOOCCH_2COOH$ and $H_2NCH_2CH(CH_3)NH_2$

C. $HOOCCH_2CONH_2$ and $CH_3CH(CH_3)NHCOOH$

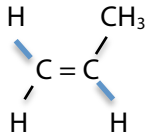
D. $HOOCCH_2COOH$ and $H_2NCHC(CH_3)NH_2$

Q23 structures:

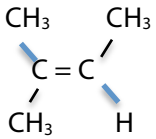
1-fluoro-1-bromoethene



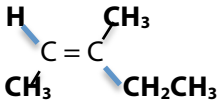
Propene



2-methylbut-2-ene



3-methylpent-2-ene



End of Section One

Section Two: Short Answer **70 marks (35% of paper)**

This section has 11 questions. Answer all questions. Write your answers in the spaces provided.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page
- Continuing an answer. If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

Suggested time for working for this section is 60 minutes.

Question 26 **[6 marks]**

(a) Describe one chemical test that may be used to distinguish between the two colourless liquids methanol and methanal. State the observations with each chemical.

Test: **REACT WITH CONC H_2SO_4 AND ETHANOIC ACID**

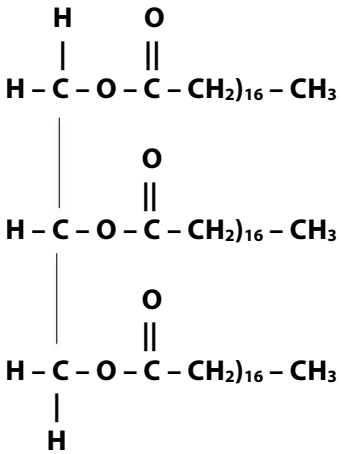
Boiling point – not acceptable

Observation with methanol: **SWEET FRUIT SMELL**

Observation with methanal: **NVR**

[3 marks]

(b) A soap has the formula $CH_3(CH_2)_{16}COONa$. Draw the structure of the triester (triglyceride) that this soap was prepared from.



What must be added to this triester to produce soap? **NaOH(aq) / KOH(aq)**

[2, 1 marks]

Question 27 **[4 marks]**

Iron (III) chloride dissolves in water to form a pale brown solution. Over time, a brown precipitate of $Fe(OH)_3$ is formed, establishing the following equilibrium:

$$Fe^{3+}(aq) + 3H_2O(l) \rightleftarrows Fe(OH)_3(s) + 3H^+(aq)$$

(a) Give one observation when some $Fe(OH)_3(s)$ is added to above equilibrium.

More solid is present or NVR

[1 mark]

(b) What chemical could be added to a solution of iron(III) chloride to prevent the precipitation of iron(III) hydroxide? Give a reason why this would reduce precipitation.

Chemical recommended: **addition of an acid, e.g. HCl(aq)** [1 mark]

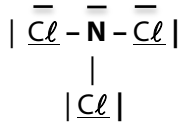
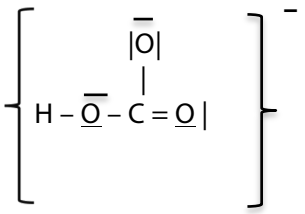
Reason:

Adding acid increases the concentration of hydrogen ions in solution and hence equilibrium will shift to the left to reduce the hydrogen ion concentration and hence limits the forward reaction, the precipitation of iron (III) chloride.

[2 marks]

Question 28 **[4 marks]**

For each species listed in the table below, draw the structural formula, representing all valence shell electron pairs as : or as –

Nitrogen trichloride, $NC\ell_3$	Hydrogencarbonate ion, HCO_3^-
	

Question 29 **[7 marks]**

(a) The first ionisation energies of five **consecutive** elements of the Periodic Table are shown below.

Element	First Ionisation Energy (kJ mol^{-1})
V	1310
W	1680
X	2080
Y	495
Z	733

Which element in the above table would be a halogen? **W** [1 mark]

(b) Place the following in order of increasing 1st ionisation energy

Mg, Na, Cs, Cl, P **Cs < Na < Mg < P < Cl** [1 mark]

Give an explanation for your answer.

I.E depends on the nuclear charge and the radius of the atom / ion. ✓

Across a period the I.E increases hence Na < Mg < P < Cl due to the increase in the nuclear charge ✓ hence the stronger force of attraction between the nucleus and the valence electrons which are all in the same principle energy level. ✓

Down a group the I.E decreases hence Cs < Na. Although the nuclear charge increases ✓, the electrons are much further from the nucleus in a higher principle energy level ✓ and (shielding effect increases) hence the force of attraction for the valence electrons are weaker leading to a lower I.E value.

[5 marks]

Question 30 **[6 marks]**

(a) Write ionic chemical equations for the following: [2,2 marks]

(i) The reaction between a green solid and a colourless solution that produces a colourless gas and a blue solution.

$$CuCO_3(s) + 2\,H^+(aq) \rightarrow Cu^{2+}(aq) + H_2O(l) + CO_2(g)$$

(ii) Excess cobalt(II) nitrate solution is added to sodium phosphate solution.

$$3\,Co^{2+}(aq) + 2\,PO_4^{3-}(aq) \rightarrow Co_3(PO_4)_2(s)$$

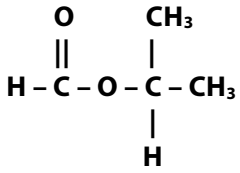
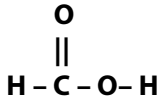
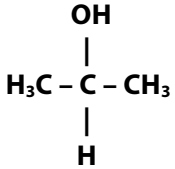
(b) Give complete observations for the reaction that occurred in (ii) above. [2 marks]

Pink solution is added to a colourless solution, <u>pink precipitate forms</u> and the solution <u>remains pink</u>.

Question 31 **[6 marks]**

A sweet smelling liquid, **A**, has a molecular formula $C_4H_8O_2$. **A** was prepared from reacting liquids **B** and **C** in the presence of concentrated H_2SO_4.

Liquid **C** when oxidised by MnO_4^-/H^+ produced a ketone.

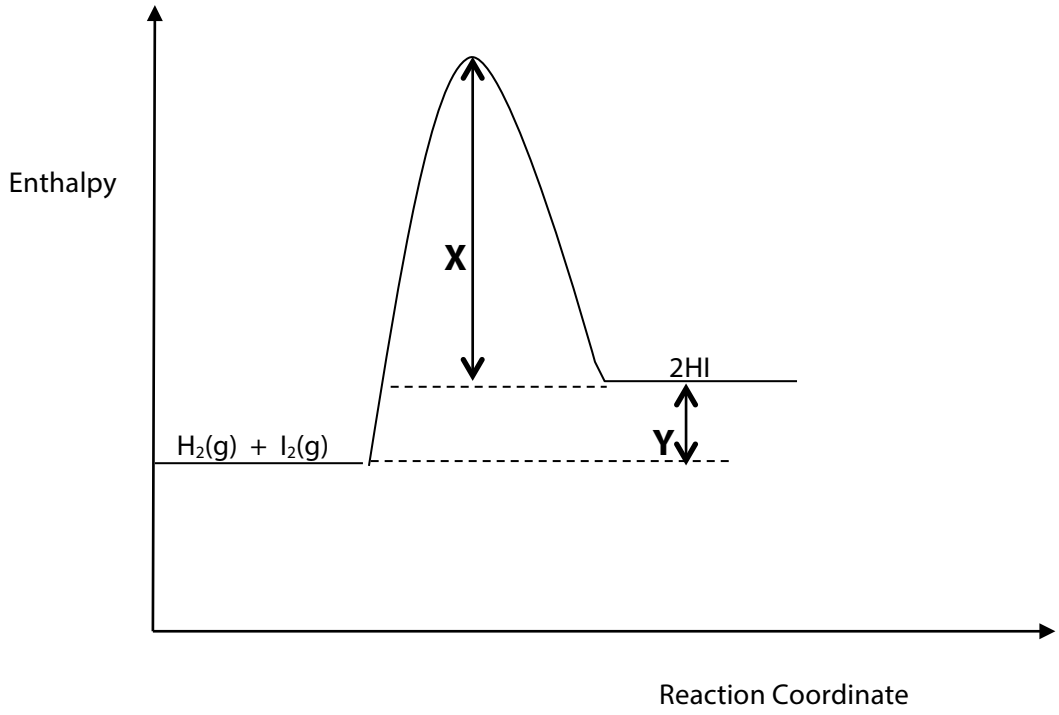
Name of Liquid **A** **2-propylmethanoate**	Structure of Liquid **A** 
Name of Liquid **B** **Methanoic acid**	Structure of Liquid **B** 
Name of Liquid **C** **Propan-2-ol**	Structure of Liquid **C** 

Question 32 **[6 marks]**

Shown below is the energy profile diagram for the reversible reaction:

$$H_2(g) + I_2(g) \rightleftarrows 2HI(g)$$

Answer the following questions in terms of X and Y. You may have to use > (greater than) and < (less than) signs in your responses.



(a) What is the enthalpy change [ΔH] for the forward reaction? **Y**

(b) What is the enthalpy change [ΔH] for the reverse reaction? **–Y**

(c) What is the activation energy for the forward reaction? **X + Y**

(d) What is the activation energy for the reverse reaction? **X**

(e) What is the ΔH for the forward reaction if a catalyst is used? **Y**

(f) What would be the activation energy of the pathway provided by a catalyst for the forward reaction? **< (X + Y)**

Question 33 **[7 marks]**

Aluminium (Al), magnesium (Mg), sulfur (S_8) and phosphorus (P_4) are all elemental solids in period 3 of the Periodic Table.

List the melting points of these solids in *increasing* order **$P_4 < S_8 <$ Mg < Al**

[1 mark]

Justify your answer

Melting points depends on the strength of the bonds which need to be disrupted during the Phase change. The stronger the bonds, the higher the melting point. ✓

Mg < Al: Metallic bonds present which are strong bonds between cations and delocalised electrons hence their m.pt is higher than the covalent molecules. ✓

The melting point of metals depends on the size of the cationic charge and the radius. ✓
As they are both in the same period the radius is similar but Al is 3+ where as Mg is 2+, hence Al has the higher m.pt. ✓

$P_4 < S_8$ Both are non-polar covalent molecules with weak dispersion forces between molecules, it is the strength of the dispersion forces which determines m.pt in this case. ✓
The strength of dispersion forces increases with an increase in the number of electrons in the molecule, hence $P_4 < S_8$. ✓

[6 marks]

Question 34 **[8 marks]**

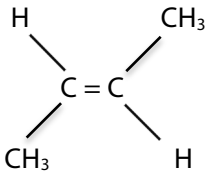
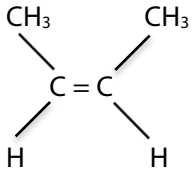
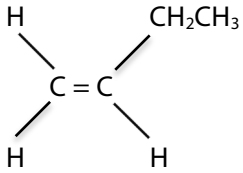
Three hydrocarbons **X**, **Y** and **Z** undergo addition reactions with HBr(g).

Hydrocarbons **X** and **Y** gives a **single** product 2-bromobutane.

On addition reaction with HBr compound **Z** can produce two products, **T** and **L**.

L is also 2-bromobutane.

Complete this table:

Compound	Structure	IUPAC Name
X		**trans – but-2-ene** **or cis – but-2 ene**
Y		**trans – but-2-ene** **or cis – but-2 ene**
Z		**But – 1– ene**
T	$Br - CH_2 - CH_2 - CH_2 - CH_3$	**1-bromobutane**

Question 35 **[11 marks]**

Chlorine reacts with carbon monoxide as follows:

$$C\ell_2(g) + CO(g) \rightleftarrows COC\ell_2(g) \qquad \Delta H < 0$$

(a) Consider the imposed changes described below and identify the change which has occurred to the total pressure in the container, the concentration of CO and the mass of CO, once equilibrium has been re-established. Complete this table by writing increase, decrease or no change.

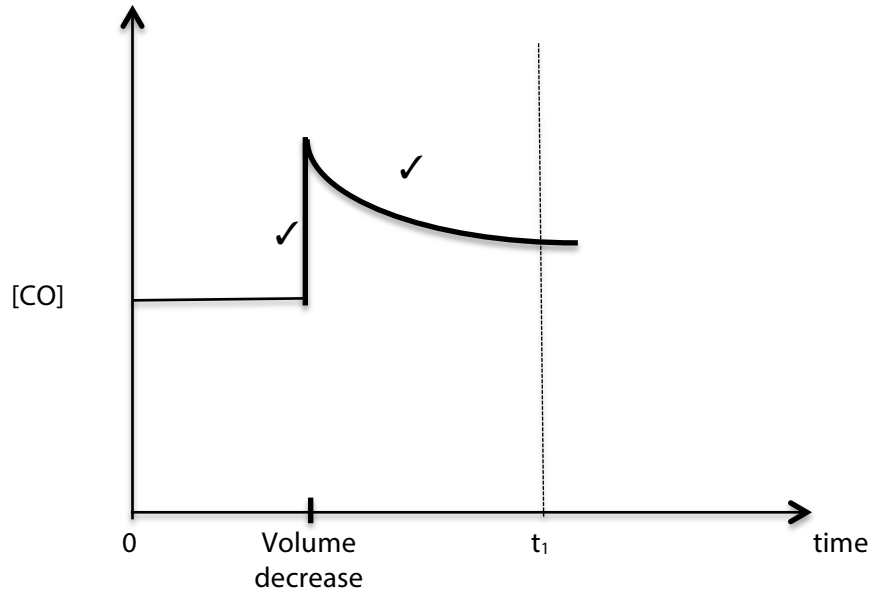
[9 marks]

Imposed Change	Total pressure in the container	Concentration of CO	Mass of CO
(i) The volume of the container is decreased	**increase**	**increase**	**decrease**
(ii) The temperature of the system is increased	**increase**	**increase**	**increase**
(iii) Ne(g) is added at constant volume	**increase**	**No change**	**No change**

NOTE: " – " is not accepted as an answer ; use words

(b) Complete the sketch below for imposed change (i) until equilibrium is re-established at t_1.

[2 marks]



Question 36 **[5 marks]**

A and **B** are both amino acids.

A : H_2NCH_2COOH and **B**: $H_2NCH_2CH_2COOH$

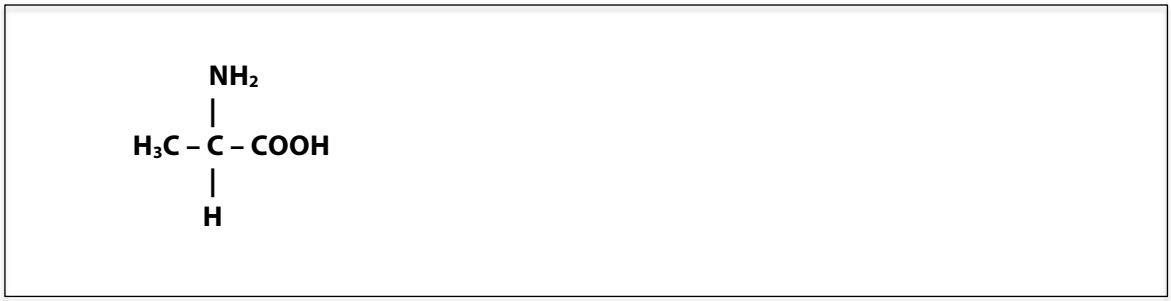
(a) Which of the two amino acids above is **not** an α-amino acid? **B**

[1 mark]

Justify your choice

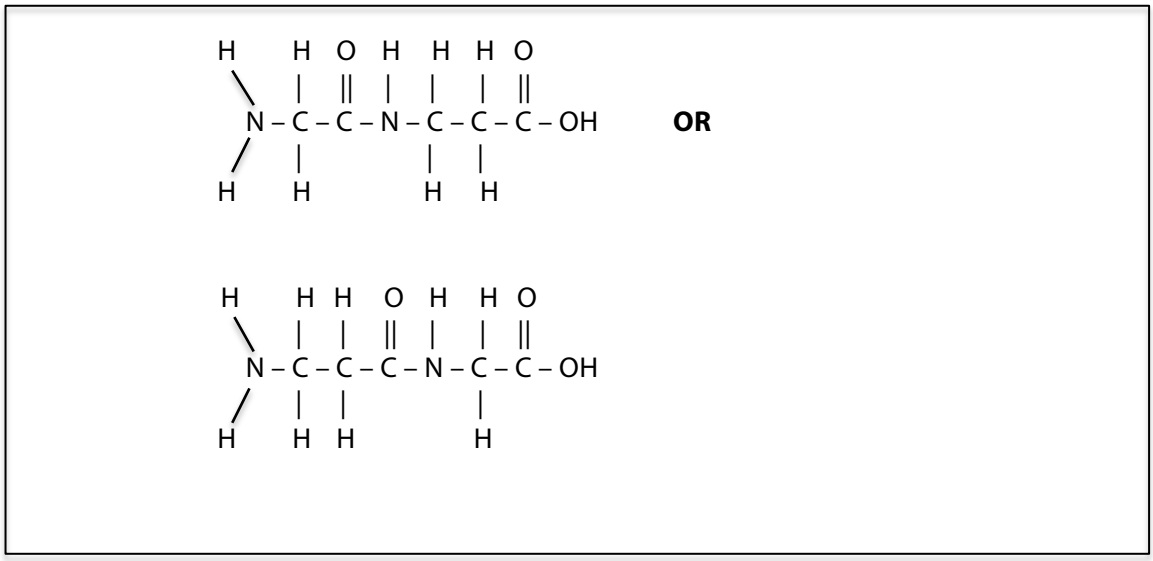
An α-amino acid must have the NH_2 and the COOH groups attached to the same carbon. B has them on two different carbons. [1 mark]

(b) The non α-amino acid identified in (a) can be redrawn as an isomer that is an α-amino acid. Draw this isomer. [1 mark]



(c) Dipeptides are the major organic product formed when two amino acids react. Draw one dipeptide formed in the reaction between **A** and **B**.

[2 marks]



(1 mark if a polymer structure given with correct peptide bond)

End of Section Two

Section Three: Extended answer **80 marks (40% of paper)**

This section contains **five** questions. You must answer **all** questions. Write your answers in the spaces provided.

Where questions require an explanation and/or description, marks are awarded for the relevant chemical content and also for coherence and clarity of expression. Lists or dot points are unlikely to gain full marks.

Final answers to calculations should be expressed to three (3) significant figures.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.
•Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
•Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

Suggested working time for this section is 70 minutes.

Question 37 **[19 marks]**

2.42 g of substance **X,** containing only the elements carbon, hydrogen and oxygen was divided into two equal samples. The first sample, on complete combustion in a dry stream of oxygen produced 3.03 g of carbon dioxide. The second sample produced 1.24 g of water under the same experimental conditions.

(a) Determine the empirical formula of substance **X**.

$n(CO_2) = 0.0688$ **mass C = 0.827 g ✓**

$n(H_2O) = 0.0688$

n(H) = 0.1377 **mass H = 0.1388 g ✓**

mass O = 1.21 – m(C) – m(H)

= 0.244 ✓

n(O) = 0.01525 ✓

	C	H	O
moles	**0.0688**	**0.1377**	**0.01525**
Ratio (÷ 0.01525) ✓	**4.51**	**9.03**	**1**
X 2	**9**	**18**	**2**

Empirical Formula is $C_9H_{18}O_2$ ✓

[6 marks]

Question 37 continued

(b) When vapourised, a 0.650 g sample of **X** was found to occupy 48.1 mL at a pressure of 213 kPa and temperature of 27°C. Determine the molecular formula of **X**.

n $= \frac{PV}{RT} = \frac{213 \ x \ 0.0481}{8.314 \ x \ 300.15}$ **= 0.04106** ✓

M = mass / moles = 0.650 / 0.0 4106 = 158 g mol^{-1} ✓

M($C_9H_{18}O_2$) = 158.234 ✓

hence the molecular formula is $C_9H_{18}O_2$ ✓

[4 marks]

(c) Substance **X** is an ester. Write a balanced equation showing how the ester ethylpropanoate could be made.

$$CH_3CH_2OH + CH_3CH_2COOH \xrightarrow{H^+} CH_3CH_2COOCH_2CH_3 + H_2O$$

(must have water for 2 marks) [2 marks]

(d) When the ester 1-octylmethanoate is treated with concentrated acid, two substances **Y** and **Z** are made.

Complete the table below giving the structural formula of **Y** and **Z**.

[2 marks]

Structure	Solubility in water
HCOOH **methanoic acid**	Miscible
$CH_3(CH_2)_6CH_2OH$ **octan-1-ol**	Immiscible

Question 37 continued

(e) Give a full account of the bonding present in pure samples of ethanoic acid and hexan-1-ol and explain the difference in their solubility in water.

[5 marks]

Ethanoic acid – intermolecular forces present H-bonding (highly electronegative O bonded to H), dipole-dipole (C=O) and dispersion forces. ✓

Hexan-1-ol – intermolecular forces present H-bonding (O bonded to H) and dispersion forces. ✓

Water also contains hydrogen bonds between water molecules. Ethanoic acid, being a small molecule will be soluble in water since it will form hydrogen bonds with water. ✓

On the other hand hexan-1-ol is a larger molecule and although the hydrogen bonds between water and hexan-1-ol are the drive force for mixing, the dispersion forces in the alcohol are over a significant area. These dispersion forces cannot compete effectively with the hydrogen bonding between water molecules and hence water and hexan-1-ol are only partially miscible. ✓✓

Question 38 **[14 marks]**

0.452 g of a mixture of barium chloride and barium hydroxide was dissolved in water and made up to a volume of 50.0 mL. This solution required 14.3 mL of 0.115 mol L^{-1} hydrochloric acid for neutralisation.

(a) Determine the moles of barium hydroxide in the 0.452 g mixture. [3 marks]

$H^+(aq) + OH^-(aq) \rightarrow H_2O$

n(HCl) **= 0.115 x 0.0143 = 0.00164** ✓

= n(OH^-) present in barium hydroxide ✓

n($Ba(OH)_2$) **= ½ n(OH^-)**

= 8.22 x 10^{-4} ✓

(b) Determine the mass of barium chloride in the 0.452 g mixture. [2 marks]

m($Ba(OH)_2$) **= n x 171.316** **=** **0.141 g** ✓

m($BaCl_2$) **= 0.452 – 0.414** **=** **0.311 g** ✓

(c) What is the concentration of barium ions in solution after neutralisation? [5 marks]

n(Ba^{2+}) from $Ba(OH)_2$ **= 8.22 x 10^{-4}** ✓

n(Ba^{2+}) from $BaCl_2$ **= 0.311 / 208.2** **=** **0.00149** ✓

n(total) **= 2.313 x 10^{-3}** ✓

c(Ba^{2+}) = n/v **= 2.313 x 10^{-3} / 0.0643** ✓ **for volume**

= 0.0360 mol L^{-1} ✓

-1 mark overall for incorrect use of significant figures for this question

Question 38 continued

(d) What volume of 0.0500 mol L^{-1} of silver nitrate solution would be required to precipitate the chloride ions from the solution after the addition of HCl(aq)?

[4 marks]

$n(Cl^-)$ from $BaCl_2$ = 0.00189 x 2 = 0.00298 ✓

$n(Cl^-)$ from HCl = 0.00164

$n(Cl^-)$ in total = 0.00298 + 0.00164 = 0.00464 ✓

= $n(AgNO_3)$ ✓

$V(AgNO_3)$ = n/c = 0.00464 / 0.05 = 0.0925 L ✓

Question 39 **[11 marks]**

Sodium azide, NaN_3, is used in car airbags and escape chutes in aircraft and decomposes at high temperature to produce nitrogen gas. Sodium metal produced in the reaction subsequently reacts with potassium nitrate and silicon dioxide to produce harmless substances, including potassium and sodium silicate glass. The reactions involved and their percentage efficiencies are shown below.

Reaction 1: $2\ NaN_3 \rightarrow 2\ Na + 3\ N_2\ (g)$ 97%

Reaction 2: $10\ Na + 2\ KNO_3 \rightarrow K_2O + 5\ Na_2O + N_2\ (g)$ 99%

Reaction 3: $K_2O + Na_2O + 2\ SiO_2 \rightarrow K_2O_3Si + Na_2O_3Si$ 92%
silicate glass

If 80.0 g of sodium azide are used in a typical airbag calculate the following:

(a) The number of moles of sodium produced in reaction 1. [2 marks]

$n(NaN_3)$ = 80 / 65.02 = 1.23 ✓

n(Na) = 1.23 x 0.97 = 1.19 moles ✓

(b) The number of moles of potassium oxide produced in reaction 2. [2 marks]

$n(K_2O)$ = 1/10 x n(Na) x 0.99 = 0.118 ✓ **for 1/10 and** ✓ **for 0.99**

Question 39 continued

(c) The mass of the sodium silicate glass, Na_2O_3Si, produced in reaction 3. [2 marks]

$n(Na_2O_3Si)$ = $n(K_2O)$ x 0.92

= 0.118 x 0.92

= 0.108 ✓

$m(Na_2O_3Si)$ = 0.108 x 122.07

= 13.2 g ✓

(d) The volume of nitrogen gas produced at 101.3 kPa and 25°C. [5 marks]

From Reaction 1: $n(N_2)$ = 3/2 n(Na) = 3/2 x 1.19

= 1.785 ✓

From reaction 2: $n(N_2)$ = $n(K_2O)$ ✓

= 0.118

$n(N_2)$ in total = 1.908 ✓

V $= \frac{nRT}{P} = \frac{1.908 \ x \ 8.314 \ x \ 298.15}{101.3}$ ✓

= 46.7 L ✓

or direct ratio used: $n(N_2)$ = 16/10 x n(Na) x 0.97 x 0.99 = 1.89
V(N2) = 46.3 L

3 marks max if N_2 from reaction 2 given only (2.89 L)

3 marks max if N_2 from reaction 1 given only (43.7 L)

Question 40 **[17 marks]**

Methanal (CH_2O) is an important industrial chemical. It is made by the oxidation of methanol:

$$2\ CH_3OH(g) + O_2(g) \rightleftarrows 2\ CH_2O(g) + 2\ H_2O(g) \qquad \Delta H = -570 kJ\ mol^{-1}$$

(a) If the temperature of a sample of this system at equilibrium is raised what effect will this have on the value of the equilibrium constant K? Give the equilibrium expression and explain the effect of temperature change.

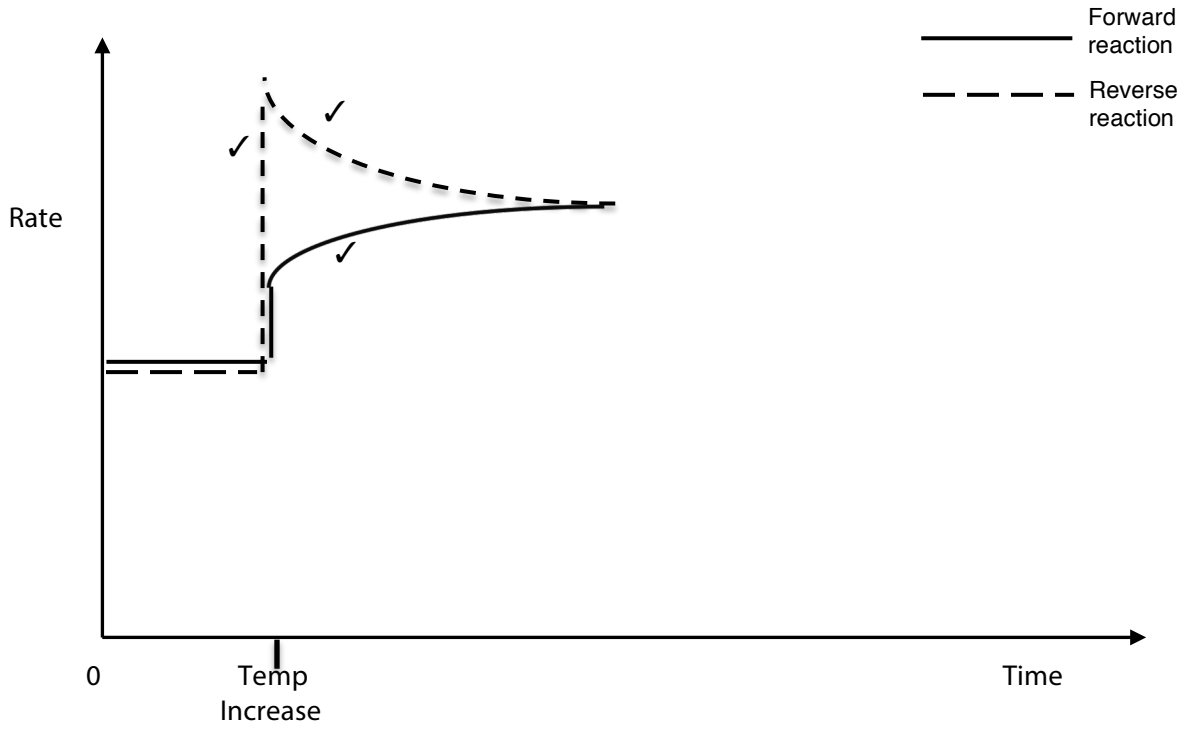
[1,2 marks]

$$\mathbf{K = \frac{[H_2O]^2\ [CH_2O]^2}{[CH_3OH]^2\ [O_2]}}$$

Explanation:

AS TEMPERATURE IS INCRESAED THE ENDOTHERMIC REACTION IS FAVOURED ✓ WHICH IS THE REVERSE IN THIS CASE ✓, HENCE LESS PRODUCTS ARE FORMED AND THE K VALUE WOULD DECREASE. ✓

(b) Complete the graph to show the changes in reaction rate associated with an increase of temperature in the sample until equilibrium is re-established.



[3 marks]

Question 40 continued

(c) Predict what temperature and pressure conditions (high, low or moderate) would be most favourable for producing methanal industrially and explain your prediction using the Collision Theory and Le Chatelier's Principle.

[6 marks]

TEMPERATURE:
A high temperature will increase the rate of the reaction by increasing the frequency of collisions and providing more particles with energy greater than the minimum for reaction. ✓

Since the forward reaction is exothermic, a low temperature will increase the yield of methanal since the system will favour the reaction which will increase the temperature of the system which will be an exothermic reaction.✓

A compromise is required between rate and yield so a <u>moderate temperature</u> is recommended. ✓

PRESSURE
A high pressure will increase the rate of the reaction by increasing the frequency of collisions leading to a faster rate of reaction. ✓

A low pressure will favour the yield since the system will try to counteract this by shifting to the side with the most number of gaseous molecules, which is the forward reaction (3:4).✓

A compromise is required between rate and yield so a <u>moderate pressure</u> is recommended. ✓

Question 40 continued

(d) Propanal, an aldehyde, can be made commercially by reacting carbon monoxide, hydrogen gas and ethene in the presence of a catalyst. In the laboratory, propanal can be made using propan-1-ol in a different reaction to that used commercially.

(i) Give details for the reagent(s) needed for the laboratory preparation of propanal from propan-1-ol and any observations that could be expected.

[1,1 marks]

Reagents: **acidified MnO_4^- or acidified $Cr_2O_7^{2-}$ ✓**

Observation: **acidified MnO_4^- : PURPLE TO COLOURLESS ✓✓ or**

acidified $Cr_2O_7^{2-}$: ORANGE TO GREEN

(ii) If propan-1-ol is added in excess but all other reactants are in the correct stoichiometric ratios, both propanal and propan-1-ol will be present in the final mixture. State a suitable method to separate the two liquids and explain your choice.

[1,2 marks]

Separation method:

Distillation (fractional) ✓

Explanation:

The liquids will have different boiling points. Propan-1-ol has hydrogen bonding between molecules and hence will have a higher boiling point ✓than propanal which has, as it main IMF, dipole-dipole forces acting between the molecules. ✓The dipole-dipole forces are weaker than the hydrogen bonds in the alcohol and hence propanal will be distilled off first.

Question 41 **[19 marks]**

The physical properties of substances can be explained using knowledge of bonding and atomic structure.

(a) Examine the table of physical properties for a number of elements and their associated oxides.

Element	Melting Point (°C)	First Ionisation Energy (MJ mol^{-1})	Electrical conductivity (MS m^{-1})	Oxide and melting point (°C)
Sodium	98	0.49	20	Na_2O 801
Potassium	63	0.43	14	Not given
Germanium	937	0.77	10^{-6}	GeO_2 1150
Chlorine	-101	1.25	0	ClO_2 -59

(i) State and explain the type of bonding present in germanium. [3 marks]

Germanium will be a covalent network substance. ✓

It has a very low electrical conductivity and hence could not be a metal ✓.

It has a high melting point and so it could not be a covalent molecule, hence the properties are indicative of a network structure. ✓

(Germanium cannot be ionic as it is NOT a compound. It is an element and so can only be metallic, covalent molecule, covalent network or atomic)

Question 41 continued

(ii) Explain why sodium has a higher first ionisation energy than potassium. [2 marks]

Although potassium has more protons, there is an increase in shielding going down a group so the effective nuclear charge of K is reduced and the dominating factor is the radius of the atom. ✓ The valence electron in potassium is in the 4th principle energy level and hence further from the nucleus than in sodium (valence electron is in the 3rd energy level), hence it will be easier to remove the most loosely bound electron in potassium. ✓

(iii) Explain why both sodium and potassium have high electrical conductivity while germanium and chlorine have conductivities that are effectively zero. [2 marks]

Sodium and potassium are both metals and have delocalised electrons in a lattice of positive ions. Conductivity requires mobile charge particles and hence metals conduct since the electrons are mobile. ✓

Covalent molecules (Cl_2) and covalent network substances (Ge) have their valence electrons localised in the covalent bond or as lone pairs of electrons (Cl_2) and hence have no mobile charge carriers to allow for conductivity. ✓

(iv) Explain why the oxides given have high melting points with the exception of chlorine. [3 marks]

Sodium oxide is an ionic compound with strong bonds between the ions and it requires a lot of energy to disrupt the ionic bond and hence it has a high melting point. ✓

GeO_2 is covalent network substance and strong covalent bonds between Ge and O need to be disrupted during melting – hence high melting point. ✓

Cl_2O is a covalent molecule with weak dipole-dipole forces of attraction between molecules. The covalent bond is not broken during the phase change, only the weak dipole-dipole forces are disrupted and hence it has a low melting point. ✓

Question 41 continued

(b) The substances below have different boiling points. In the table, rank them in order of decreasing boiling point and explain your choice.

[3 + 6 marks]

Substance	Molar mass (g mol^{-1})	Boiling points in order (1 = highest, 5 = lowest)
Hexane	86.172	**4**
Butanoic acid	88.104	**1**
2-methylpentane	86.172	**5**
Pentan-1-ol	88.146	**2**
Pentanal	86.130	**3**

5 correct – 3 marks **3 correct – 2 marks** **2 or 1 correct – 1 mark**

Explanation:

These are all covalent molecules and hence the boiling point will depend on the strength of the intermolecular forces. Since all of similar mass they have similar dispersion forces. For similar mass substances, hydrogen bonding strength > dipole-dipole forces > dispersion forces ✓

Butanoic acid has the highest since it has both hydrogen bonding and (highly electronegative O bonded to H in the molecule) dipole-dipole forces (due to the carbonyl group, C=O) acting between molecules. The presence of the two O atoms enables more places for H-bonding to occur between molecules and hence the highest b.pt✓

Pentan-1-ol, similarly has hydrogen bonding between molecules but does not have the additional O atom so it has a lower boiling point than the acid. ✓

Pentanal (presence of the carbonyl group C=O) has dipole-dipole forces between molecules which are weaker than hydrogen bonds for similar mass had so will have a lower boiling point than the alcohol. ✓

Hexane and 2-methylpentane are both non-polar molecules with dispersion forces between their molecules. ✓The more linear a structure is the stronger the dispersion forces since there is a greater surface area over which the dispersion can act and the chains can get into closer proximity to each other and so hexane will have the higher boiling point. ✓

END OF EXAM